THE STRUCTURES AND AGE RELATIONS OF THE VOLCANIC COMPLEX OF CECIL COUNTY, MARYLAND

A dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy

BY

JOHN MARSHALL

1936

THE JOHNS HOPKINS PRESS

BALTIMORE, 1937

THE STRUCTURES AND AGE RELATIONS OF THE VOLCANIC COMPLEX OF CECIL COUNTY, MARYLAND

A dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy

BY

JOHN MARSHALL

1936

THE JOHNS HOPKINS PRESS

BALTIMORE, 1937

R. UNIV.
BIBLIOTHEEK
LEIDEN

CONTENTS

Page

Part IV. The Structures and Age of the Volcanic Complex of Cecil County, Maryland. By John Marshall 189
Introduction 191
Age Relations 191
Petrography 192
Schist 192
Volcanics 193
Massive Amygdaloids 193
Sheared Amygdaloids 196
Schistose Volcanics 197
Gabbro 199
Massive Gabbro 199
Stretched Gabbro 200
Granite 201
Port Deposit Granite 201
Massive Hornblende Granite 201
Hornblende Granite 201
Granite Porphyry 201
Granite Dikes 202
Aplite Dikes 202
Structure 203
Elements of Flow 203
The Glenarm Schist 203
Volcanics 203
Gabbro 205
Granite 206
Hornblende Lamprophyre 208
Jointing 208
Summary and Conclusions 211

Digitized by the Internet Archive
in 2026

https://archive.org/details/IA41547016_0062

THE STRUCTURES AND AGE OF THE VOLCANIC COMPLEX OF CECIL COUNTY, MARYLAND

INTRODUCTION

The region described in the subsequent pages lies in the central part of Cecil County, Maryland, and extends toward the southwest across the Susquehanna River into Harford County. The area is nearly two miles wide and a little more than twelve miles long. As shown on the map (pl. XXXV) the belt of volcanic rocks varies in width and is widest where it approaches the Susquehanna River. The region is a part of the great Piedmont complex of crystalline rocks which lies between the sediments of known Paleozoic age in Pennsylvania and western Maryland and the unconsolidated deposits of the Atlantic Coastal Plain. The rocks are highly metamorphosed and bear little resemblance to the igneous intrusions which have invaded them.

The peculiarities of the volcanic rocks have been briefly described by several workers. G. P. Grimsley (44) in 1894 described the material as diorite and thought it was probably a dynamically metamorphosed gabbro. Bascom made a more detailed study in 1902 and considered it a later intrusion into the granite. She recognized the more acid character of the rock and, concluding it was a metamorphosed rhyolite, applied the term metarhyolite to the rocks of an area roughly coinciding with that shown in plate XXXV. In 1920 (12), working in the eastern part of the region, Bascom concluded that the material was not so acidic and named it metadacite, which term has also been applied in a later paper (11).

AGE RELATIONS

The age and sequence of the rocks of the complex has been determined by various workers but their results vary widely. Keyes (60) concluded that the granites are the youngest intrusives and may be anything from pre-Cambrian to epi-Carboniferous. Grimsley (44) concludes that the granites are older than the gabbro and that the volcanics, which he called diorite, are intrusive into the granite. In the published version of the paper (44) he concludes that the gabbro is the older rock. Bascom in the Cecil County report (1902) considers the sequence from older to younger to be: basic biotite-granite, metarhyolite, basic hornblende-granite, quartz-biotite-hornblende-gabbro, quartz-hornblende-gabbro, hornblende norite

and quartz norite, norite and hypersthene gabbro, pyroxenite, and peridotite. In the Elkton-Wilmington Folio (12) Bascom gives the same sequence and considers the volcanics as intrusive into the granite. The age is determined as post-Glenarm and either pre-Cambrian or Upper Silurian. In the latest paper (11) the sequence of intrusives is given as the same, but the volcanics are called extrusives and correlated with those of western Maryland described in several earlier papers (14, 15) but no age is given. Cloos and Hershey (26) have shown that the age of the intrusive rocks of the region is post-Conestoga and hence at least Lower Paleozoic, if not later, but they do not mention the volcanic complex.

The age of the Glenarm Series is still a subject of controversy. Some writers (72, 78) deny the presence of the Martic overthrust suggested by Knopf and Jonas (65) and believe the series to be Paleozoic; while others accept the hypothesis of an overthrust and consider the Glenarm Series as pre-Cambrian.

The age relations of the rocks of the complex were determined by structural methods: truncation of foliation, inclusions of older rock engulfed in intrusives, intrusive relationships of younger rocks, and contact phenomena of various kinds.

PETROGRAPHY

Most of the rock types found in the complex have been previously described. Many of the descriptions lack detail, however, and none gives the locality of the specimens so that one is never sure which type is given a certain name, especially since there is in each case more than one type of the same general composition and texture although they differ in occurrence and sometimes in age. For this reason the locality of the following specimens described will be given in some detail.

SCHIST

Of the rock types found in the complex one of the oldest is the schist which is probably of Glenarm age. This rock is well exposed at only one locality, on Principio Creek about 600 feet downstream from the Baltimore and Ohio Railroad bridge. The rock in the stream is a fine-grained, compact, chlorite schist which is worn to very smooth rounded forms by the water in spite of the softness of the material. In this respect it is in marked contrast to other schist exposures which have a ragged appearance where subjected to stream erosion. The compact structureless character of this rock is probably caused by the gabbro dikes by which the schist is intruded. In the old channel of the spillway of an abandoned mill to the east of the stream the rock resembles the Peters Creek schist as ex-

posed in the neighborhood of Peach Bottom station along the Susquehanna River. The material is not exposed in place but is scattered along the ditch. This schist is more foliated than that in the creek and has a strong fracture cleavage with a second less intense fracture cleavage superimposed on the first one. This fracture cleavage produces crinkles on the planes of the first at an angle of about 30 degrees to the trace of the schistosity which is almost obliterated by fracture cleavages.

Specimen of Glenarm schist from south side of spillway about 50 feet north of exposure in creek:

Megascopically the rock appears as a soft chlorite schist of pale brownish-green color. Specimens break out along the fracture cleavage rather than along the schistosity, owing to the sharp crinkling of the folia.

Microscopically the rock consists of finely-laminated colorless chlorite with fine-grained epidote in nearly equal amount between the folia. Occasional larger grains of epidote cut off the cleavage traces of the chlorite. Secondary magnetite occurs both in thin lenticles between chlorite plates and as bunchy aggregates cutting across the foliation.

VOLCANICS

The volcanic rocks of the area show considerable variation, megascopically grading from massive amygdaloids and even-textured volcanics through schistose amygdaloids to fine-grained hornblende schists which at times are indistinguishable from sheared gabbro except by microscopic examination. In thin sections these variations may be described as representing three types although they grade into each other. These are: a massive amygdaloid with hornblende varying from a few per cent to more than half of the rock and, as a rule, with a weak foliation; a schistose amygdaloid carrying more hornblende than the average massive type; and a schistose rock composed mostly of hornblende without apparent amygdules in the hand specimen. The minerals of all types are the same but vary in proportion according to the development of the schistosity. The primary minerals seen in thin sections are: quartz, plagioclase of a composition Ab_8An_2 to Ab_7An_3, and green hornblende with a pleochroism from light green to deep blue-green and acicular habit. The stronger the shearing the rock has undergone the greater is the proportion of hornblende. Quartz and feldspar occur in about equal proportion. Secondary minerals are usually epidote or clinozoisite and magnetite.

MASSIVE AMYGDALOIDS

Of the volcanics the most easily recognized is the massive amygdaloid. This material differs from the more schistose type in the larger proportion of quartz and feldspar and its less intense schistosity. However, the types

may grade into one another and are even found in alternating bands. Besides the inclusions of feldspar in the rock which are largely altered to epidote, there are also larger structures, up to one foot or more in diameter, composed of epidote and sometimes also of feldspar or chlorite around which the foliation is bent. Where these bodies are entirely replaced by epidote no clue as to their origin remains but in several exposures they were found in all stages of replacement with a few which were unaltered. In all such cases the amygdules have a typical structure (pl. XXXIII, fig. 1). In thin sections they are indistinguishable from the rest of the rock except for a slight increase in grain size and a somewhat lower proportion of mafic constituents. These inclusions are marked out on the periphery by a narrow zone of fine hornblende needles which decrease in number away from the inclusion to the normal amount for the inclosing rock at that place. These needles are oriented parallel to the foliation of the rock and appear to be part of it since the sharp border of the inclusions is inside this hornblende zone. Immediately inside the hornblende-rich margin the material is lighter and carries little if any hornblende. Pabst (82, p. 341) notes similar phenomena in autoliths in the Sierra Nevada granite. In most cases there is a darker zone within the light border carrying more hornblende which shows some parallelism to the foliation. The center of the inclusion is again light colored with hornblende crystals considerably larger than the others and without orientation.

Inclusions very similar to this type are found in schist of Glenarm age on the Susquehanna River to the north of the area. In the schist and in some cases in the volcanics these inclusions show a marked resemblance to the pseudo-diorite at Ducktown, Tennessee, described by Keith (58), Ross (85) and others.

Other cases were found in which these zones were lacking. The contacts in these are sharp and the material inside the hornblende-rich border is similar to the inclosing rock but entirely devoid of any foliation. In others the centers carry more mafics than the inclosing rock. Another type is nearly spherical with a well-marked dark border around a lighter colored center. The appearance of the rock suggests that these inclusions were formed while the material was still flowing since the structures do not transgress the flow lines and the platy and linear minerals within them are unoriented. Where these structures are abundant there is a certain resemblance to the pillow lavas described by Sederholm (95) in southwestern Finland. F. Corin has suggested that these inclusions may represent volcanic bombs caught in the lava.

These structures and the amygdaloidal textures are the most easily recognized features of both the massive and schistose types of volcanics.

Specimen from Stony Run 600 feet north of the Baltimore and Ohio Railroad:

Megascopically this rock is very dark gray, fine-grained, and without visible foliation either in the amygdules or the groundmass. It differs from the typical massive amygdaloid in its darker color. The rock is crowded with amygdules of feldspar and epidote which have a tendency toward a concentric structure with the feldspar in the middle. The epidote shows a radiating growth inward from the borders of the amygdules.

Microscopically the material is holocrystalline, fine-grained, with amygdules up to several millimeters in diameter in a felt of green hornblende crystals with a fine feldspar groundmass. The hornblende shows a decussate structure and, due to its prismatic character, gives the feldspar the superficial appearance of intersertal structure of a basalt. Hornblende forms over 50 per cent of the groundmass; the remainder is feldspar. This is the only specimen of the volcanic series in which quartz is not an essential constituent.

The feldspar was determined as oligoclase-andesine ($Ab_{72}An_{28}$). No orthoclase was found. The average size of the feldspar grains is about 0.1 mm. and the hornblende about 0.3 by 0.1 mm. There are a few anhedral stumpy hornblende grains of slightly larger size.

The amygdules are composed of feldspar of the same composition as that in the groundmass, partially or wholly replaced by epidote. The epidote has a weak pleochroism. It shows a radiating structure growing toward the center of the amygdule from a point slightly inside the border around the epidote and often the center of the amygdule is also a feldspar remnant. (pl. XXXIII, fig. 1).

Secondary minerals are small magnetite metacrysts less than 0.1 mm. and the epidote of the amygdules. Epidote is rare and fine-grained in the groundmass. This rock is apparently an unaltered andesite but is indistinguishable in the field from those amygdaloids which carry considerable quartz.

Specimen from the south end of Keystone quarry along the Columbia branch of the Pennsylvania Railroad:

Megascopically this rock is a medium gray, fine-grained material with discontinuous black platy streams of hornblende, giving a distinct linear and platy structure but not strong enough to develop a good cleavage. The rock therefore breaks with an uneven fracture. Epidote-bearing amygdules about 2.0 to 3.0 mm. are sparingly present.

Microscopically the material is holocrystalline, amygdaloidal, with a fine-grained groundmass and a fairly strong linear foliation due to acicular green hornblende averaging about 0.5 by 0.05 mm. The groundmass is a fine-grained mosaic of quartz and feldspar averaging less then 0.1 mm.

The amygdules are of feldspar some of which at least is orthoclase partly or wholly replaced by epidote which occurs as unoriented inclusions in the feldspar and as radial aggregates replacing it. The hornblende occurs mostly in needles but also as anhedral masses of larger size and makes up about 33 per cent of the slide. It partly bends around amygdules and is partly cut off by them.

The feldspar of the groundmass occurs as anhedral grains of less than 0.1 mm. but larger than the quartz. It was determined as an acid plagioclase, probably oligoclase-andesine.

The quartz, in somewhat smaller grains than the feldspar, shows no strain shadows and is hence probably recrystallized since the rock has undergone strain. Quartz is more abundant than feldspar. Apatite is questionably present in very small quantity as an accessory.

Secondary minerals are the epidote which occurs in fine aggregates and small crystals in the groundmass as well as in the amygdules and magnetite metacrysts occurring in the amygdules.

SHEARED AMYGDALOIDS

The schistose type of amygdaloid is so intimately mixed with the massive type that the two can not be separated in mapping. The amygdules are no more elongated than in the massive type and either remain as eye-shaped inclusions in the schist or are broken and stretched out. They do not show evidence that the vesicles were more elongated in the parent rock. Hence the schistosity of this type seems to be due to later metamorphism of parts of the volcanic rather than an original difference in the two types.

This second type carries a larger proportion of hornblende than the first and has a much more pronounced schistosity. Both the amygdules and inclusions are completely altered to epidote with occasional hornblende and magnetite. The hornblende of the groundmass is usually segregated in bands alternating with bands of quartz and feldspar, giving the rock the appearance of a flow banded lava with the flow planes bending around the amygdules. These bands vary in width from one millimeter to over a centimeter but in any one specimen are of about the same width. With a higher degree of metamorphism the banding is destroyed and the rock grades into an amygdaloidal hornblende schist, which in turn grades into a schist in which the amygdules are no longer visible megascopically although remnants of the structure may be seen under the microscope.

Specimen of schistose amygdaloid from Principio Creek about 5000 feet north of Philadelphia Road:

Megascopically this rock is dark-gray, fine-grained, and highly stretched. It is banded with alternating black layers of hornblende and gray layers of quartz and feldspar. These layers have a wavy structure and bend around the amygdules which are composed of quartz and epidote somewhat fractured and rolled out. In weathering the amygdules stand out as lumps on the surface of the rock. The hornblende

---

FIG. 1.—Photomicrograph of amygdaloidal structure in metaandesite. Parallel nicols, specimen 145.

FIG. 2.—Photomicrograph of schistose volcanics. Parallel nicols, specimen 9.

FIG. 3.—Photomicrograph of basal sections of tremolite in granulose rock. Parallel nicols, specimen 29.

FIG. 4.—Photomicrograph of myrmekitic intergrowth in granite. Crossed nicols, specimen 17.

FIG. 5.—Photomicrograph of porphyritic texture of contact phase in granite. Crossed nicols, specimen 46.

FIG. 6.—Photomicrograph of linear structure in hornblende granite. Parallel nicols, specimen 125.

layers are more resistant than the others, resulting in a series of black ridges and gray depressions on the weathered surface. The outstanding characteristic of the fresh material is its extreme stretching.

Microscopically this specimen shows bands composed mostly of hornblende needles about 1.5 by 0.05 mm. separated by a crushed amygdule of quartz and epidote in a band of fine-grained quartz and feldspar. The rock is holocrystalline, almost schistose. Hornblende is the most abundant mineral, constituting about 50 per cent of the rock. It occurs in the dark bands in small acicular crystals embedded in a fine-grained groundmass of quartz and feldspar and in the more acidic layers as poikiloblastic anhedral masses. It is partly altered to chlorite. Quartz is next in abundance to hornblende, occurring in the groundmass in fine anhedral grains less than 0.1 mm. and in the amygdules as grains with sutured boundaries about 0.3 mm. showing no strain shadows. Feldspar is slightly less abundant than quartz. It was determined, in some cases at least, to be about oligoclase-andesine. The grains are slightly larger than the quartz and contain many fine inclusions of epidote. In the groundmass it is very similar in size and appearance to the quartz. Epidote is rare in the groundmass but makes up over half of the amygdules, occurring as a finely granulated mass. Magnetite occurs in the amygdules in octahedra less than 0.1 mm. and as fine disseminated grains in the groundmass. It is apparently secondary.

SCHISTOSE VOLCANICS

The schistose type of volcanics is at the end of the series of increasing schistosity. Amydules no longer are visible in the field and the rock has a laminated structure and much more perfect cleavage than the two preceding types. The color is distinctly green in the fresh material due to the abundance of green hornblende and a certain amount of chlorite. The Bayview greenstones exposed on Northeast Creek near Bayview fall into this class although in many cases the schistosity is almost lacking. They are composed mainly of hornblende, chlorite, and epidote. Although somewhat massive they grade imperceptibly into the truly schistose type to the south. The most typical examples of these schistose amygdaloids are confined to contacts and shear zones, a circumstance suggesting that the increased schistosity of various types is a local and secondary feature. While the rocks show no evidence of amygdaloidal structure in the field, in thin sections traces of amygdules are frequently noted (pl. XXXIII, fig. 2).

Specimen from Susquehanna River ⅜ mile north of Frenchtown, inclusion in granite porphyry dike in stream bed:

Megascopically the rock is apparently included in the dike but the body is large enough not to have been altered much more than the other rocks of the type found near contacts. It is a dark gray, fine, even-grained rock with a distinctly laminated structure and very regular cleavage. The lamination is caused by light and dark layers less than 0.1 mm. thick.

Microscopically the material is holocrystalline, fine-grained nearly equigranular and schistose. The lamination is due to a higher concentration of green hornblende

crystals in the darker layers with a nearly perfect linear orientation. In the lighter layers quartz and feldspar are more abundant than hornblende. Occasional larger grains of feldspar are crushed and partly granulated. Secondary growths of magnetite and chlorite are also larger than the average grain size. Hornblende is the most abundant mineral, making up about half of the rock. It is acicular in habit, green with a pleochroism from light yellowish-green to deep blue-green and an average size of 0.8 mm. by less than 0.1 mm. A mosaic of quartz and feldspar makes up most of the remainder of the rock. The grains are about 0.1 mm. but longer than wide and have their long dimension parallel to the foliation. The feldspar was determined as oligoclase, about Ab_8An_2. Quartz and feldspar are about equal. The larger feldspar grains, about 1.0 mm., are granulated and show orientation at small angles to the foliation as if they have been rotated by shearing in the rock. Secondary minerals are irregular magnetite-chlorite aggregates up to 0.5 mm. transgressing the foliation, fine disseminated magnetite in the groundmass, and a few small anhedral grains of epidote.

Specimen from east side of the Susquehanna River about 30 feet south of the north volcanic-granite contact:

Megascopically this rock closely resembles the previous specimen and also occurs near the contact of a granite porphyry dike. In hand specimens it is almost black with a laminated structure due to finer darker layers. The grain is fine and even with a good cleavage parallel to the schistosity.

Microscopically the rock is holocrystalline with a schistose texture caused by biotite plates in a fine-grained groundmass of quartz and feldspar. Elongated lenticular bodies of quartz and feldspar with little biotite are apparently crushed and rolled out amygdules. The felsic minerals of the groundmass are slightly elongated and oriented parallel to the schistosity. Poikiloblastic hornblende up to 0.2 mm. occur, usually parallel to the foliation but sometimes at an angle to it.

Biotite makes up somewhat less than 50 per cent of the rock and reaches an average size of 0.2 mm. in its greatest dimension. Quartz is slightly more abundant than feldspar. It shows no strain shadows and is clear. The average dimensions are about 0.1 by 0.07 mm. The felspar grains are slightly larger and a few crushed individuals of greater dimension are present. It is crowded with fine inclusions of epidote. The composition was determined by extinction angles as oligoclase-andesine, Ab_7An_3 to Ab_6An_4. Secondary minerals beside the few green hornblendes are magnetite, chlorite aggregates up to 0.1 mm. which transgress the foliation, fine anhedral magnetite, and the epidote inclusions in the feldspar.

Specimen from Susquehanna River, Keystone quarry, at the contact of a gabbro dike:

Megascopically this material is a very light gray, fine, even-grained rock with larger crystals of magnetite scattered through it in the fresh material. In weathering it turns brown and develops a much more ready cleavage. The platy cleavage of the fresh material is poor but it has a distinct linear structure due to fine colorless acicular minerals up to a millimeter or so in length which have an almost parallel alignment. This rock resembles the inclusions of arenaceous sediments in the granite south of Conowingo dam (26) more than any other rock found in the area but is probably a contact metamorphic phase of the volcanics.

Microscopically this specimen is holocrystalline, fine-grained granulose with only a faint suggestion of foliation since it is cut normal to the linear minerals nearly all of which are parallel. The slight foliation is cut normal to the linear minerals nearly all of which are parallel. The slight foliation is due in part to linear minerals at

an angle to the majority and to the longer dimensions of the felsic constituents which lie almost in the same plane (pl. XXXIII, fig. 3).

The essential minerals are tremolite, quartz, and feldspar. The tremolite for the most part shows basal sections due to the orientation of the slide in the rock, but occasional crystals are cut parallel to the length. The average cross section is a little over 0.1 mm. and they range up to 1.0 mm. in length. Slight alteration to chlorite is present. The tremolite constitutes somewhat under 30 per cent of the rock. Feldspar is slightly more abundant than quartz and occurs in grains from 0.3 to 0.1 mm. It is oligoclase, about Ab_8An_2, in part at least. Quartz is less abundant, smaller in size 0.1 mm., and shows no strain shadows.

Secondary minerals are clinozoisite in subhedral grains about 0.1 mm., magnetite in octohedra and anhedral grains of about the same magnitude, and magnetite chlorite aggregates up to 2 mm.

GABBRO

The gabbroic rocks of the area have been described in Harford County as metagabbro and in Cecil County as gabbro. The only difference is a variation from a massive type to a highly stretched type, a phenomenon which appears to be local and due to shearing and contact action rather than to an original difference in the rock.

MASSIVE GABBRO

The massive gabbro occurs in dikes in the volcanics and is the more common one in Cecil County. In most places it shows a weak flow structure thus grading over to the second type but occasionally it is found without any foliation. The material is medium grained with the mafic constituents usually green hornblende, showing greater size. The foliation, when present, is caused by the parallel alignment of these minerals. Analyses of gabbros from the area in question are not available but those to the north, which have been carefully studied, do not differ except that they show somewhat less alteration. These gabbros to the north are both normal and quartz-bearing (11 and 54). The gabbros associated with the volcanic complex usually carry considerable quartz but in at least one case it is lacking. Alteration in the gabbro has been discussed by Insley (54), Bascom (1902), Jonas and Knopf (64), and Watson (102).

Specimen of gabbro near contact, southwest side of Keystone quarry, Susquehanna River:

Megascopically the rock is mottled dark-green and white with a medium coarse, even grain. It has a fair foliation due to the parallel alignment of the mafic constituents but has no regular cleavage.

Microscopically the rock is holocrystalline hypidiomorphic with a medium and uneven grain. Larger stumpy hornblende crystals are embedded with little parallel orientation in a fine groundmass of feldspar and quartz.

Essential minerals are hornblende, feldspar, and quartz. The hornblende consti-

tutes slightly over 50 per cent of the rock. It has a characteristically broad stumpy habit and is only partially idiomorphic. Its color is light green and the pleochroism is much less marked than in the hornblende of the volcanics. The feldspar was determined as bytownite Ab_1An_9. In most cases, however, the borders of the grains are altered to albite and some are entirely replaced. Quartz is about equal to feldspar in abundance and shows no strain. The grain size of the groundmass averages about 0.1 mm.

Epidote in fine grains in the groundmass is the only important secondary mineral. Magnetite is rare.

Specimen from Northeast Creek along the southern volcanic-granitic contact 1 mile southeast of Bayview:

Megascopically this rock is dark greenish-gray with dark green equant phenocrysts of hornblende about 1 mm. in size. It shows no foliation at all in the specimen although there is an indefinite banding of finer grained streaks in the outcrop. The groundmass is fine-grained. It is dark gray and weathers to a greenish-gray.

Microscopically the rock is holocrystalline inequigranular. Both the feldspar of the groundmass and the hornblende phenocrysts show cataclastic effects, the hornblende in particular. In many cases it is bent and in one place in the slide one of the crystals is rolled almost into a circle, the effects figured by Harker (48, p. 354) as typical of cataclastic metamorphism.

The essential minerals are green hornblende and feldspar. The hornblende constituting over 50 per cent of the slide reaches a size of about 1.5 mm. and is nearly equant. Its pleochroism is weaker than in the volcanics; yellowish to yellow-green. Partial alteration to chlorite is present. The feldspar is largely replaced by epidote and is fine grained, about 0.1 mm. The few grains on which measurements were possible seem to fall between andesine and labradorite, according to extinction angles normal to 010 and index of refraction. Quartz was not found.

Secondary minerals are clinozoisite in anhedral grains of about 0.05 mm. making up about 30 per cent of the slide, and irregular masses of magnesite associated with chlorite as filling in cracks in the hornblende. It is partly altered to brown hydrous iron oxides.

STRETCHED GABBRO

The more highly stretched type of gabbro differs from the massive variety in its more intense foliation and tendency to a finer grain. With decreasing grain size the stretched gabbro becomes exceedingly difficult to distinguish from the schistose type of volcanics and even in thin section there is no marked difference. The volcanics are slightly finer in grain and the habit of the hornblende is somewhat different. The hornblende of the volcanics is acicular and more or less idiomorphic with a strong pleochroism. In the gabbro it is also acicular but shows less developed crystal form, is more fractured, and has usually a weaker pleochroism. The feldspars of the gabbro are so extremely albitized that they can not be used for determination of gabbroic character.

Specimen from the east side of the Susquehanna about 500 feet south of Keystone quarry:

Megascopically the material is dark greenish-gray with a speckled appearance due to the hornblende and feldspar. It has a slight brownish stain from weathering. Linear stretching is pronounced with a rigid parallel alignment of the hornblende. A dike of aplitic material about 1 cm. thick runs through one corner of the specimen and is probably derived from the granite which is exposed a short distance to the south.

Microscopically the thin section of this specimen shows a rock of holocrystalline, nearly equigranular character. Its texture is medium-grained gneissose. The hornblendes are larger than the rest of the grains and are nearly parallel.

The essential minerals are hornblende, making up about 50 per cent of the rock, and feldspar and quartz in nearly equal amounts. The hornblende grains tend to be shorter and wider than those of the volcanics and some show a poikiloblastic structure. These are fractured and stretched out in the line of foliation. Pleochroism is fairly strong yellow-green to blue-green. The average size is 1 mm. by 0.5 mm. The feldspars range in size from 1.0 to less than 0.1 mm. The larger individuals show Carlsbad twinning and oriented inclusions of hornblende, the structure to which Sederholm (96, p. 45) gives the term symplectite. The feldspar was determined as having the composition of oligoclase Ab_8An_2. Quartz is nearly as abundant as feldspar. The average size is 0.2 mm. It shows a tendency to segregation in irregular bands and in some cases shows undulatory extinction. A few grains of magnetite are associated with the hornblende.

GRANITE *

Later than the gabbro is the granite complex in which the following three types may be distinguished in larger bodies and three other types in dikes: Port Deposit granite, massive granite, hornblende granite, granite dikes, granite porphyry, and aplite dikes.

The *Port Deposit granite* is intrusive discordantly into both gabbro and volcanics, transecting the foliation of the older rocks. In addition xenoliths of gabbro are found locally torn off the walls near the contact with the granite. Larger bodies of volcanics are found in the granite near contacts and are apparently loosened from larger masses of wall rock.

The *massive hornblende granite* is found in dikes intrusive into the volcanics. These are abundant on Stony Run and Northeast Creek. On Stony Run, south of the railroad, inclusions of gabbro occur in this granite.

The *hornblende granite* is not found in association with gabbro. However, its relations to the volcanics are clear. Xenoliths of volcanics occur in Principio Creek and the granite is found intrusive into the volcanics in small stringers. Along contacts the volcanics are quite schistose and the granite fine grained with a strong linear flow structure.

The *granite porphyry* differs from the other granitic dikes in color and

* Ed. Note: The term "granite" is here used loosely as a group name for the rocks of the granodiorite complex described in part II of this volume.

texture. Microscopically, it is finer grained and the feldspars have a different habit. The occurrence of the dikes is similar to that of the granite dikes described above and in addition the granite porphyry forms plug-like intrusions. In a few cases it cuts the wall rock foliation at a high angle. Inclusions of the volcanics are found locally. This material shows intrusive relationships to all the older rocks except the schist. It is common as dikes in the gabbro, granite, and in the volcanics.

The *granite dikes*, which are distinguishable in the field from granite porphyry by their lighter color and large quartz grains, nearly parallel the schistosity of the wall rock. They are intrusive into the volcanics. On Northeast Creek east of Leslie, this rock has soaked into a banded and crinkled material which is probably a schist member of the Glenarm Series. Little altered inclusions of schist showing a distinct fracture cleavage occur in the granite.

The *aplite dikes* are intrusive into the granite, gabbro, and volcanics. Within the granites their foliation is parallel to that of the granite although the dike contacts maybe at an angle to it. This would seem to indicate that the dikes were probably formed during a late stage of the granite intrusion. In the volcanics the foliation of the dikes parallels their contacts though the dikes may be at any direction in the country rock. In the gabbro the aplites occur in tiny stringers without foliation and are oriented in all directions.

The youngest intrusive rock is a hornblende lamprophyre. It occurs in small dark fine-grained dikes in all the rocks of the region except the schist. The larger dikes generally strike parallel to the schistosity of the wall rocks. Smaller stringers may transect the country rock in any direction.

The age of various types of veins found in the region is mostly uncertain but some small pegmatites are associated with the granite porphyry. They were not found in the lamprophyres.

Dikes of diabase correlated with the Triassic intrusions to the north and

---

FIG. 1.—Photomicrograph of porphyritic texture and zonal growth. Crossed nicols, specimen 57.

FIG. 2.—Photomicrograph of bending in hornblende in massive gabbro. Parallel nicols.

FIG. 3.—Photomicrograph of granite porphyry. Crossed nicols, specimens.

FIG. 4.—Photomicrograph of cataclastic structures in sheared granite porphyry. The fractures in the large garnet crystal are walled by quartz. Crossed nicols, specimen 63.

FIG. 5.—Photomicrograph of mylonitic granite porphyry. Parallel nicols, specimen 36.

FIG. 6.—Photomicrograph of hornblende lamprophyre from south face of Keystone quarry. Parallel nicols.

west occur in the granite near Port Deposit and at other localities but none was found in the area covered by this paper.

STRUCTURE

ELEMENTS OF FLOW

Under elements of flow are included both primary structures due to movement of plastic material during intrusion and secondary schistosity due to metamorphism which has, in many cases, obscured the primary structures that were present. The degree of metamorphism varies with the different rock types but in no case were rocks found that were free from all evidence of deformation. Flow structure and allied phenomena of the rocks of the region will be discussed with the rock types in which they are developed.

THE GLENARM SCHIST

The Glenarm schist was found in only one small outcrop. Near the inclosing gabbro it loses its characteristic fracture cleavage and becomes more dense. The rock is a highly foliated chlorite schist with a strong fracture cleavage, transgressing the flow cleavage at about an angle of 45 degrees. The closeness of the cleavage planes and the amount of displacement along them has almost obscured the schistosity and fracturing takes place along the fracture cleavage planes rather than along the schistosity. The development of fracture cleavage in the Glenarm Series on the Susquehanna River has been discussed by Cloos and Hershey (26). The schist on Principio Creek shows great similarity to the schist of the Glenarm Series except that the flow cleavage is more intense. In addition there is a second fracture cleavage developed which produces fine crinkles on the planes of the first one.

The schist is intruded by small dike-like bodies of dark fine-grained rock. These resemble the hornblende lamprophyre but may be aphopyses of the gabbro which borders the schist on the north and south sides. The gabbro to the south becomes strongly foliated and gneissic near the contact though apparently not sheared. This probably is a primary border gneiss of the gabbro formed during a late stage of intrusion. Away from the contact the gabbro is more massive though there is a tendency to banding and other flow structure.

VOLCANICS

Flow structures in the volcanics are largely secondary. All alignment of the minerals must be due to secondary processes since the minerals them-

selves are secondary. Knopf and Anderson (61) describe similar textures in andesite roof pendants at Engels, California, as secondary and due to metamorphism. Traces of primary structures, however, are preserved in the shape and orientation of amygdules and inclusions which are mostly parallel to the later schistosity. The shape of both amygdules and inclusions is, as a rule, lenticular but without an excessive length-width ratio; an indication that flow was not strong in the primary lava. There has been little stretching of these bodies since. No cases were found in which amygdules had been either broken and pulled apart or stretched into elongated bodies as have, for instance, the pebbles of the Cardiff conglomerate near Whiteford in Harford County. Where the amygdules are deformed they are crushed and rolled out into lenticular streaks of fragments to such an extent that the amydgaloidal character has been lost. As noted earlier, this extreme deformation seems to be limited to zones of shearing or contacts and is not due to regional metamorphism. Other exposures show amygdaloids without any deformation although the rock is thoroughly recrystallized. Additional evidence of the restriction of the deformation to local zones is furnished by the wide variations in strike of the schistosity over short distances. Later intrusions in the form of plugs or dikes seem to have bent and deformed the older rock to conform to their contacts. Where straight dikes occur bending of the wall rock schistosity is rare. This, however, may be due to the small angle between the dikes and the general strike of the country rock.

Actual contacts in the region are rarely exposed and hence mapping must be done by distribution and structural features of outcrops interpreted in the light of their behavior where contacts can be seen. Exposures of strikingly discordant contacts between the volcanics and later rocks are few. The exposed contacts are generally conformable to the foliation of the volcanics. Where later intrusions cross the strike of the volcanics they do so by interfingering and "lit-par-lit" injection. This manner of intrusion has resulted in the splitting off of small bodies of volcanics which are found as dike-like bodies outside the main mass. This "lit-par-lit" type of contact is somewhat similar to that described by Cloos (28) between the Ellicott City granite and the Wissahickon schist.

The original nature of the volcanic complex has been obscured by the later intrusions and their shattering of the volcanic rocks. However, while the large structural features have been largely obliterated, smaller structures often remain. The most important of these is the amygdaloidal character of the material. The development of this structure is so widespread and characteristic that there can be little doubt that the original rock has been vesicular. According to Bowen vesiculation in a rock of any

thickness can be developed only in a flow but not in dikes. These rocks are, as a rule, several hundred feet thick and, except for a few later dikes which cut them, may attain thicknesses of more than a mile. Therefore they must have been formed as flows and not as dikes, as suggested by previous workers (44). Since flows do not form with dips from 70 to 90 degrees these must have been tilted or folded into their present position. If the body is a fold the folding, like that of the Peach Bottom syncline, is isoclinal but no general change in the dip or strike indicating a fold is recognizable.

The strike readings given in the following pages are simplified as follows: readings are taken in degrees from 0 to 180 degrees clockwise with 0–180 degrees at the north. Thus a reading of 45 degrees represents a direction 45 degrees east of north and one of 135 degrees a direction of 45 degrees west of north.

The general strike of the volcanics changes gradually from west to east, the banding in the flow structures showing a tendency to form a fan pattern opening to the east. On both sides of the Susquehanna River the strike is uniformly about 40 to 50 degrees. On Mill Creek it is about 55 to 60 degrees. This strike persists through the central part of the volcanic complex. In the southern half the strike shows a tendency to swing more to the east and in the northern half it tends more northward.

In the eastern portion of the area there is little change in the general strike of the foliation but there is a marked flattening in the dip both in the granite and the volcanics.

GABBRO

In the large body of gabbro in Harford County, to the southwest of the volcanic complex, the foliation is parallel to the schistosity of the volcanics where it joins them near the Susquehanna River. West and south of this region the strike bends to the north, following roughly the outline of the granite body which partly underlies the town of Havre de Grace.

The gabbro dikes within the volcanics are extremely variable. Their foliation may or may not parallel the schistosity in the wall rock or the contacts of the dike. As a rule, however, the dikes are parallel to the schistosity of the volcanics or cut it at a low angle and the foliation of the dike is parallel to the contact. Many of these dikes are exposed along the Susquehanna River and a few along other streams.

The contacts of gabbro and volcanics are always sharp and usually mark a zone of shearing accompanied by a development of strongly schistose and crushed rocks in the volcanics. These zones are in several localities the channels for later intrusives.

GRANITE

The character of the granite foliation varies with the rock type. Port Deposit granite, in which the mafic constituents are mostly mica, has a well developed platy foliation with a weaker linear direction due to the shape of the mica folia (p. 42). In the hornblende and massive granites, on the other hand, the shape of subparallel hornblende crystals favors strong linear flow lines with a weaker planar structure due to a slight deviation from a parallel alignment of the hornblende in the plane of the foliation. Inclusions in all the granites parallel the foliation when the shape of the inclusions is elongate or tabular. Equidimensional inclusions show no orientation (26). These inclusions are both autoliths and xenoliths in all three granites. According to Hershey (Part II of this volume) the directions expressed by the foliation and inclusions are lines of primary flow and not due to subsequent metamorphism. In this case it is to be expected that granite will cut off structures in older rocks where the two are not parallel.

Contact relations between the volcanics and granite are poorly exposed and in most of the localities studied the structures of both rocks are parallel. Locally, however, the contact is discordant and the structure of the granite parallels the contact while the schistosity of the volcanics is truncated. This is well shown by the "closing in" of the granite foliation on either side of the nose of the volcanic complex at its northeastern end. The intertonguing relationships where the contact crossed the strike of the volcanics has been described. This same type of contact occurs apparently between gabbro and granite, as is shown on the contact of the two south of the Keystone quarry north of Havre de Grace. Here the contact is parallel with the granite foliation and cuts that of the gabbro about 30 degrees. However, the distribution of the granite is such that, if the contacts are parallel with the foliation, the granite and gabbro must be intertongued. The same type of contact relations are clearly shown between gabbro and volcanics about 200 feet north of this locality.

That intertonguing contacts are not always developed on a small scale is shown by the bending of the strike of the volcanics around the nose of a granite body several hundred feet in width on the little stream three-eighths of a mile north of Frenchtown.

In the granite dikes the structures are quite simple and uncomplicated. There is a fairly distinct linear orientation and at times a weak planar foliation due to a majority of the hornblende crystals lying in the same plane. The foliation in all observed cases is parallel with the contacts. The contacts do not always parallel the foliation of the volcanics though they were not observed to cut the wall rock foliation at very high angles.

In the aplites, which occur only as small dikes, there is some variation in the intensity of foliation depending on the occurrence of the material and the parent granite with which it is associated. The aplites in the Port Deposit granite carry biotite and muscovite in tiny flakes and are quite massive. In the hornblende granite the aplites contain acicular hornblende with a fairly good foliation parallel to that of the inclosing granite regardless of the direction of the dikes. Where aplites are intrusive into the wall rock they have a fairly strong foliation, which is parallel to the walls of the dike, whether this direction cuts the foliation of the inclosing rock or is parallel to it.

The granite porphyry, while probably related to the granodiorite intrusions, is later and intrusive into them. It occurs in dikes from a few inches to about 75 feet thick. These dikes are most abundant along the Susquehanna River and the lower part of Principio Creek but are found also over the whole area. Along the Susquehanna River in Harford County they strike parallel to the wall rock structure. On Principio Creek where the strike of the volcanics swings more to the east they cut it, striking roughly parallel to the dikes at the river. On Stony Run the strike of both volcanics and porphyry is extremely irregular. One exposure shows a curving dike with the foliation of the volcanics following its contact. Probably the great variation in readings is due to the valley of the creek cutting across these curved dikes. Another type of variation is due to plug-like intrusions of the porphyry. Farther to the east the dikes are fairly regular and intrude the volcanics nearly parallel to their schistosity. The exposed contacts are sharp and the foliation of the dike, where it is developed, is parallel to the contacts except in cases of plug-shaped intrusions. The foliation of the wall rock is never cut at a high angle but is usually nearly parallel, apparently due to bending around of the wall rock schistosity since a short distance away there may be considerable difference between the strikes of the foliation of wall rock and dike. No dikes were found with exposed terminations but the frequency of exposures showing "lit-par-lit" injections of porphyry into volcanics seems to indicate that in most cases the dikes feather out into the wall rock.

The foliation of the porphyry can vary between a very weak and a very strong linear or planar structure. The latter occurs in dikes which have undergone considerable deformation. Shear zones of granite or gabbro are frequently marked by dikes of porphyry in the central portion. These dikes show strong cataclastic structures and schistose margins. The dike contacts have apparently been lines of weakness along which later movements have taken place. Contacts of other types are also loci of movement and in several cases have been the spaces into which the porphyry found its way. Inclusions in the porphyry are rare and in all cases are schistose volcanic rocks.

HORNBLENDE LAMPROPHYRE

The structures in the basic dikes in the region vary between a rather strong linear foliation with a weaker planar one due to the alignment of hornblende and a material in which no foliation is visible megascopically. Under the microscope all specimens show at least a trace of parallel hornblende crystals.

Where the foliation is visible it is usually parallel to the contacts. In the small irregular dikes in the gabbro the lamprophyre is generally too fine grained and massive to show any arrangement of minerals. The larger dikes have a fairly strong foliation in the central portion. The margins of these show chilled borders, finer grained and darker than the rest of the rock.

The dikes are mostly intruded parallel to the schistosity of the wall rock. Exceptions are found striking at a low angle to the foliation of gabbro, granite, and volcanics. In addition to these larger dikes there are small injections in the gabbro which are extremely irregular and have no relation to the foliation of the inclosing rock. These are well developed along the west side of the Susquehanna River. A dike of the same rock, but with a more pronounced planar foliation, occurs here intrusive into granite porphyry and cutting it at a small angle. The planar foliation in this dike, and also occasionally found in others, is due to the development of mutually parallel chlorite crystals. At least one case has been observed in which the strike of the lamprophyre is controlled by the schistosity of the wall rock. On the small stream three-eighths of a mile above Frenchtown a dike of the lamprophyre occurs in the volcanics which are here bent around the end of a tongue of granite. The dike follows the foliation of the volcanics and its strike changes from 60 to 50 degrees within a distance of about 100 feet.

JOINTING

Jointing is abundant in the area. In all the rock types there are two dominating joint systems and others that are less widespread and some which are peculiar to certain rock types.

The two most important sets are those joints parallel to the strike and dip of the foliation and those nearly at right angles to the first and with a nearly vertical dip. The first set is present in all the rock types of the region but varies greatly in different rock types. They are most frequent and closely spaced in the volcanics, displaying considerable movement. In the gabbro and granite they are more widely spaced and in the dike rocks are usually inconspicuous although generally present. These joints are of considerable extent and more conspicuous than any other system.

Slickensiding is practically always present and indicates normal faulting. The set is later than the intrusion of the youngest rocks. Shear zones occur frequently in the same direction. Every gradation between the joints and shear zones is represented. In the volcanics zones of intense deformation, with the production of crush rocks and mylonite, die out into closely spaced planes of movement in solid rock which become more widely spaced farther away. Rarely are these joints more than a few feet apart in the volcanics. In the granite and gabbro they are less numerous but also grade into zones of shearing. The shear zones are frequently marked by dikes of granite porphyry which is intensely sheared along the margins and shows a strong foliation in the center. These sheared dikes are common in granite and gabbros. In the volcanics the dikes are little altered but the adjoining wall rock is highly sheared.

In addition to the slickensiding, indicating normal faulting on the strike joint faces, there is in places a second weaker direction of slickensiding which shows nearly horizontal movement. This is later than the regional tension joints and offsets them to a considerable extent. In one locality the offset has been about 2 feet on each joint, where they are about 2 feet apart. This movement appears to be local and has been effective over a small area. Where the rocks are exposed considerable creep is developed, producing an appreciable change in dip of both the foliation and joints.

The second important joint system is extremely uniform over the entire area. The joints are large, even, fairly widely spaced, and vary little in strike and dip over considerable distances. Except in one case where there are slickensides showing a nearly horizontal displacement, they show no evidence of movement. They tend to be slightly open and their surfaces are often coated with calcite or zeolite. However, no instances of dikes filling the openings were observed. Along the Susquehanna River they strike uniformly about 140 to 150 degrees with a very nearly vertical dip. Farther eastward the strike swings to the east but beyond Stony Run it swings back again toward the north. The average strike on Mill Creek is about 160 degrees; on Principio Creek it is about the same; while on Stony Run it is nearer 165 degrees. Exposures are too poor to record very many readings but these are probably close to the average. Beyond Stony Run the strike swings more westward and on Northeast Creek readings of about 110 degrees are usual where these joints are exposed. Most of these joints are nearly at right angles to the strike of the foliation but the dip is nearly 45 degrees to that of the linear schistosity; also they are developed equally in all rocks, hence they can not be primary cross joints. They have, however, the appearance of tension joints. The uniformity over a wide area and their other characters suggest that they are regional tension joints formed after the intrusion of the granites.

Another set of joints which is well developed both in volcanics and gabbro, and to lesser extent in other rock types, is composed of horizontal joints. These are common but rarely of large extent with great variation in strike and changing in dip from 0 to about 20 degrees except where they are developed on a hill side. Here the jointing often follows the topography. The number of these joints decreases with depth. Leith (68) describes joints of this type as being due to compression, the jointing being developed with removal of load by erosion. It seems reasonable to interpret these joints as exfoliation joints, since they remain always parallel with the present surface.

Another system of joints is sporadically well developed over this area. This set has a strike slightly south of east, with little variation over the region, and a dip from 60 to 70 degrees south. On a joint-strike diagram they show as a slightly variable group of joints striking at about 30 degrees east of the regional tension joints.

Primary jointing, except for the widespread strike joints, is not common. The only good examples noted in the area are in the granite porphyry dikes. These show both cross joints and diagonal joints in a few instances. The cross joints are developed in a plane normal to the orientation of the flow lines. They do not extend into the wall rock. These characters fit the definition of cross joints, that is primary joints due to tension during intrusion. They have very plane surfaces and show no evidence of movement.

The diagonal joints occur also in granite porphyry but not together with the cross joints. They are small, closely-spaced, and tight. Except where weathering has stained the surfaces they are often blind joints; that is, they are not visible but the rock will break along them. The traces of these joints on the platy foliation is normal to the linear foliation with an angle of about 45 degrees between the plane of the planar structure and the joint surface. The tightness of these joints and their development near the centers of the dikes is evidence that they are not feather joints, which are due to tension. The number of these joints, in the few localities in which they occur, is small.

Joints of origins besides those already described are few and small. Feather joints (29), that is open diagonal joints due to tension along a plane of movement with the acute angle between the joint and the fault plane pointing in the direction of movement, are found along small faults in several places. Neither the fault nor feather joints are of any great extent. The faults rarely show displacements of more than a few feet, and have apparently little relation to the structure. A few larger movements occur in the granite in a few cases with displacements in tens of feet.

One exception to normal faulting was noted. Here a small thrust is developed striking parallel to the foliation but dipping at a lower angle. Slickensiding shows that a reverse movement has taken place. The strike joints cross this thrust plane and offset it. Hence it must be older than the joints. The slickensides indicate a movement parallel to the linear foliation of the gabbro; that is, pitching about 50 degrees east. Small feather joints also indicate reverse faulting. A thin film of mylonitic material occurs on the plane of the thrust.

TABLE OF AGE RELATIONS

Rock Type	Inclusions	Intruded by
Hornblende lamprophyre	*Younger*	
Aplite		
Granite porphyry	Volcanics	Lamprophyre
Granite dikes	Glenarm schist	
Hornblende granite	Volcanics	Aplite Granite porphyry
Massive granite	Gabbro	
Port Deposit granite	Gabbro	Lamprophyre Granite porphyry Aplite
Gabbro		Lamprophyre Granite porphyry Aplite Pegmatite
Glenarm schist		Gabbro Granite dikes
Volcanics	*Older*	Lamprophyre Aplite Granite porphyry Granite dikes Hornblende granite Massive granite

SUMMARY AND CONCLUSIONS

In the course of the present investigation it was found that the area is not composed entirely of one rock type as it had been mapped. Several of the other rock types which are present in other parts of the Piedmont

Province were found in the area and are apparently of Glenarm age which had not been previously recognized.

There are at least seven rock types which vary rather markedly. The oldest of these are the schists. They bear a close resemblance to those of the Glenarm Series which are well exposed on the Susquehanna River at Peach Bottom station, north of the Pennsylvania line, and which are also found as inclusions at Conowingo Dam (p. 119). These schists show well developed fracture cleavage and in all respects resemble those of the Peters Creek formation. Apparently of about the same age are the volcanics, the diorite of Grimsley, or the metarhyolite and metadacite of F. Bascom. Into the volcanics is intruded a gabbro which has been described by Leonard (70), Insley (54), and F. Bascom (11). The gabbro has been separated into gabbro and metagabbro. In this area the gabbro shows a strong linear structure while the metagabbro is rather massive. Both are altered. These have been intruded by several granites which range in composition from biotite to hornblende granite. The granites in turn are intruded by dikes of granite porphyry and later by hornblende lamprophyre. The granite porphyry was recognized by Bascom and called "micro-granite." Within the granite are small aplite dikes later than the granite but of uncertain relations to the other rocks. There are also probable apophyses of the main granite mass.

The structure of the volcanics apparently indicates the trough of an isoclinally folded syncline remaining as roof pendant in the surrounding Port Deposit granite complex. In this case the schist occurring in the central portion of the belt of volcanics must originally have overlain them. This would make the volcanics Peters Creek in age or older. Volcanics of the same type are common in the limestones of Carroll County, Maryland, and it seems probable that the Cecil County volcanics are to be correlated with them. In this case the Wissahickon formation is missing, but this is true in other localities and may be so in Cecil County. Whatever the actual position may be there can be little doubt that the volcanics belong to the Glenarm Series and that they have been folded into their present position.

The intrusion of the Port Deposit complex has taken place after this folding into the position it now occupies. These inclusions are believed to have taken place during post-Conestoga times.

The rocks of the region have been considered by many workers as highly metamorphosed and the foliation described as secondary, but the only highly metamorphic rocks are the volcanics and schists of Glenarm age and portions of the Baltimore gneiss. The structures of the intrusives are largely primary. The gabbro shows considerable alteration but largely dependent on local movements such as shear zones.

The metamorphism of all the later rocks of the area consists in a moderate cataclastic deformation. Locally it increases in intensity with the production of mylonite along zones of shearing. These shear zones show normal faulting.

The history of the region may be summarized as follows: Glenarm volcanics and schists were folded into isoclinal folds, slightly overturned to the northwest. Fracture cleavage developed after folding. The gabbro was then intruded largely following structures in the older rocks, mostly in small dikes. The gabbro apparently did not split up the volcanics or stope off blocks from the walls. The following intrusion of the Port Deposit igneous rocks broke up the edges of the volcanics, intruding them "lit-par-lit" and splitting off long narrow fragments. The direction of the flow of the granite was very nearly parallel to the strike of the fold. The dikes intruded after the granite followed these lines and intruded both volcanics and granite about parallel to their foliation. Veins and pegmatites formed after the dike intrusion. After the last intrusion there was sufficient deformation to form shear zones along the lines of foliation and develop cataclastic structures in varying degrees throughout the area.

LITERATURE REFERENCES

(1) Adams, F. D. and Barlow, A. E. Geology of the Haliburton and Bancroft Areas. Province of Ontario. Canadian Geol. Survey, Memoir 6, 1910, 419 pp.

(2) Agar, W. M. The Petrology and Structure of the Salisbury-Canaan District of Connecticut. Amer. Jour. Sci., vol. 23, 1932, pp. 31–48.

(3) Balk, Robert. Structural Behavior of Igneous Rocks. Geol. Soc. Amer., Memoir 5, 1937.

(4) ———— Structure Elements of Domes. Amer. Assoc. Petrol. Geol., Bull. 20, 1936, pp. 51–67.

(5) ———— Structural and Petrologic Studies in Dutchess County, New York. Part I. Geol. Soc. Amer. Bull. 47, 1936, pp. 685–774.

(6) ———— Viscosity Problems of Igneous Rocks. Jour. Rheology, vol. 3, 1932, pp. 461–478.

(7) ———— Structure and Correlation of Metamorphic Rocks in Southeastern New York. Nat. Acad. Sci. Proc. vol. 18, 1932, pp. 616-630.

(8) ———— Die primäre Structur des Noritmassivs von Peekskill am Hudson, nördlich New York (auch bekannt als "Cortlandt Norit"). Neues Jahrbuch f. Min. etc., B: B., 57-B, 1927, pp. 249–303.

(9) ———— Primary Structures of Granite Massives. Geol. Soc. Amer. Bull. 36, 1925, pp. 679-696.

(10) Barth, Tom, F. W. Structural and Petrologic Studies in Dutchess County, New York. Part II. Geol. Soc. Amer. Bull. 47, 1936, pp. 775-850.

(11) Bascom, F. The Pre-Cambrian Igneous Rocks of Eastern Pennsylvania and Maryland. Trans. Amer. Geoph. Union. 16th Ann. pt. 1, 1935, pp. 328-350.

(12) Bascom, F. Description of the Elkton-Wilmington Quadrangle. U. S. Geol. Survey Atlas, Elkton-Wilmington Folio, No. 211, 1920.

(13) ———— Piedmont District of Pennsylvania. Geol. Soc. Amer., Bull. 16, 1905, pp. 289–328.

(14) ———— The Ancient Volcanic Rocks of South Mountain, Pennsylvania. U. S. Geol. Survey, Bull. 136, 1896, 124 pp.

(15) ———— The Structures, Origin, and Nomenclature of the Acid Volcanic Rocks of South Mountain. Jour. Geol., vol. 1, 1893, pp. 813-832.

(16) Becker, G. F. Experiments on Schistosity and Slaty Cleavage. U. S. Geol. Survey, Bull. 241, 1904, 34 pp.

(17) ———— Finite Homogeneous Strain, Flow and Rupture of Rocks. Geol. Soc. Amer., Bull. 4, 1893, pp. 13-90.

(18) Behre, Charles H., Jr. Slate in Pennsylvania. Penn. Geol. Survey, 4th Ser. Bull. M16, 1933, 400 pp.

(19) Billings, Marland. Structural Geology of the Eastern Part of the Boston Basin. Amer. Jour. Sci., vol. 18, 1929, pp. 97–137.

(20) Bliss, E. F. and Jonas, A. I. Relation of the Wissahickon Mica Gneiss to the Shenandoah Limestone and Octoraro Schist of the Doe Run and Avondale Region, Chester County, Pennsylvania. U. S. Geol. Survey, Prof. Paper 98-b, 1917, pp. 9-34.

(21) Bowen, N. L. The Origin of Ultra-basic and Related Rocks. Amer. Jour. Sci., vol. 14, 1927, pp. 89-108.
(22) ——— The Behavior of Inclusions in Igneous Magmas. Jour. Geol. vol. 30, 1922, pp. 513 570.
(23) Bubnoff, S. von. Geologie von Europa. Vol. 2, pt. 1, 1930, 660 pp.
(24) Chester, F. D. The Gabbros and Associated Rocks in Delaware. U. S. Geol. Survey, Bull. 59, 1890, 45 pp.
(25) Cloos, Ernst. Der Sierra-Nevada-Pluton in Californien. Neues Jahrb. B.B. 76, Abt. B, 1936, pp. 355-450.
(26) Cloos, Ernst and Hershey, H. Garland. Structural Age Determination of Piedmont Intrusives in Maryland. Nat. Acad. Sci., Proc. 22, No. 1, 1936, pp. 71-80.
(27) Cloos, Ernst. Auto-Radio—An Aid in Geologic Mapping. Amer. Jour. Sci. vol. 28, 1934, pp. 255-268.
(28) ——— Structure of the Ellicott City Granite, Maryland. Nat. Acad. Sci., Proc. vol. 19, 1933, pp. 130 138.
(29) ——— Feather Joints as Indicators of the Direction of Movements on Faults, Thrusts, Joints, and Magmatic Contacts. Nat. Acad. Sci. Proc. vol. 18, 1932, pp. 387-395.
(30) Cloos, Hans. Einführung in die Geologie. Ein Lehrbuch der inneren Dynamik. Gebr. Borntträger, Berlin, 1936.
(31) ——— Plutone und ihre Stellung im Rahmen der Krustenbewegungen. XVI Internat. Congress, Rpt. vol. 1, 1935, pp. 235-253.
(32) ——— and Martin, H. Der Gang einer Falte. Fortschr. der Geol. & Pal. H. 33, 1932, pp. 74-88.
(33) Cloos, Hans. Zur Terminologie der Plutone. Fennia 50, 1928, pp. 1-28.
(34) ——— Einführung in die Tektonische Behandlung magmatischer Erscheinungen. Part I, Das Riesengebirge in Schlesien. Berlin, Gebr. Borntträger, 1925, 194 pp.
(35) Credner, H. Das sächsische Granulitgebirge und seine Umgebung. Leipzig, 1884.
(36) Dale, T. N. The Commercial Granites of New England. U. S. Geol. Survey, Bull. 738, 1923, 488 pp.
(37) ——— The Slate Belt of Eastern New York and Western Vermont. U. S. Geol. Survey, 19th Ann. Rept., pt. 3, 1899, pp. 153-307.
(38) ——— Geology of the Green Mountains in Massachusetts. U. S. Geol. Survey, Mon. 23, pt. 3, 1894, pp. 125 202.
(39) Emmons, R. C. Concerning Inclusions in Igneous Magmas. Jour. Geol. vol. 34, 1926, pp. 422-428.
(40) Fairbairn, H. W. Introduction to Petrofabric Analysis. Dept. Geol., Queen's Univ., Kingston, Ont. Mimeographed 1935.
(41) Fenner, C. N. The Mode of Formation of Certain Gneisses in the Highlands of New Jersey. Jour. Geol. vol. 22, 1914, pp. 594-612; 694-702.
(42) Geikie, A. and Teall, J. J. H. On the Banded Structure of Some Tertiary Gabbros on the Isle of Skye. Geol. Soc. London. Quart. Jour. vol. 50, 1894, pp. 645-660.
(43) Gilluly, James. Mineral Orientation in Some Rocks of the Shuswap Terrane as a Clue to their Metamorphism. Amer. Jour. Sci., vol. 28, 1934, pp. 182-201.
(44) Grimsley, G. P. The Granites of Cecil County, in Northeastern Maryland. Cincinnati Soc. Nat. Hist., vol. 17, 1894, pp. 59 67; 78-114.

(45) GROUT, F. F. and BALK, ROBERT. Internal Structures in the Boulder Batholith. Geol. Soc. Amer. Bull. 45, 1934, pp. 877–896.
(46) GROUT, F. F. Petrography and Petrology. McGraw Hill Company, New York, 1932, 522 pp.
(47) GRUBENMANN, U. and NIGGLI, P. Die Gesteinsmetamorphose. Berlin, 1924, 540 pp.
(48) HARKER, A. Metamorphism—A Study of the Transformations of Rock-Masses. Methuen and Co., London, 1932, 360 pp.
(49) ——— The Tertiary Igneous Rocks of Skye. Scotland Geol. Survey, Memoirs, 1904, 481 pp.
(50) HAWKINS, A. C Alternative Interpretations of Some Crystalline Schists in Southeastern Pennsylvania. Amer. Jour. Sci., vol. 7, 1924, pp. 355–364.
(51) HEIM, ALBERT. Geologie der Schweiz. G. H. Tauchnitz, Leipzig, 2 vols. 1919, 1922.
(52) HOBBS, W. H. On the Rocks Occurring in the Neighborhood of Ilchester, Howard County, Maryland. Diss. Johns Hopkins Univ., 1888.
(53) INGERSON, EARL. Fabric Analysis of a Coarsely Crystalline Polymetamorphic Tectonite. Amer. Jour. Sci., vol. 31, 1936, pp. 161–187.
(54) INSLEY, HERBERT. The Gabbros and Associated Intrusive Rocks of Harford County, Maryland. Md. Geol. Survey, vol. 12, pt. iv, 1928, pp. 289–332.
(55) JOHANNSEN, ALBERT. The Serpentines of Harford County, Maryland. Md. Geol. Survey, vol. 12, pt. iii, 1928, pp. 195–283.
(56) JONAS, A. I. Structure of the Metamorphic Belt of the Central Appalachians. Geol. Soc. Amer. Bull. 40, 1929, pp. 503–513.
(57) ——— Pre-Cambrian Rocks of the Western Piedmont of Maryland. Geol. Soc. Amer. Bull. 35, 1924, pp. 355–363.
(58) KEITH, A. Outlines of Appalachian Structure. Geol. Soc. Amer. Bull. 34, 1923, pp. 309–380.
(58a) ——— Production of Apparent Diorite by metamorphism. Geol. Soc. Am. Bull. 24, Abstract, 1913, pp. 684–685.
(59) KERFORNE, F. Étude Tectonique de la Région Silurienne du Sud de Rennes. Serv. de la Carte Géol. de la France, Bull. 23, no. 139, 1919, pp. 125–162.
(60) KEYES, C. R. Origin and Relations of Central Maryland Granites. U. S. Geol. Survey, 15th Ann. Rept., 1895, pp. 685–740.
(61) KNOPF, A. and ANDERSON, C. A. The Engels Copper Deposits, California. Econ. Geol., vol. 25, 1930, pp. 14–35.
(62) KNOPF, E. B. Petrotectonics. Amer. Jour. Sci., vol. 25, 1933, pp. 433–470.
(63) ——— Retrogressive Metamorphism and Phyllonitization. Amer. Jour. Sci., vol. 21, 1931, pp. 1–27.
(64) KNOPF, E. B. and JONAS, A. I. The Geology of the Crystalline Rocks of Baltimore County. Md. Geol. Survey, Baltimore County 1929, pp. 97–191.
(65) ——— Geology of the McCalls Ferry-Quarryville District, Pennsylvania. U. S. Geol. Survey, Bull. 799, 1929, 156 pp.
(66) ——— Stratigraphy of the Crystalline Schists of Pennsylvania and Maryland. Amer. Jour. Sci., vol. 5, 1923, pp. 40–62.
(67) KOSSMAT, F. Über die Tektonik des Gneisgebietes im westlichen Erzgebirge. Centralbl. f. Min., Geol. etc., 1916, pp. 158–165.
(68) LEITH, C. K. Structural Geology. Henry Holt and Co., New York. Rev. ed. 1923.
(69) ——— Rock Cleavage. U. S. Geol. Survey, Bull. 239, 1905, 216 pp.

(70) Leonard, A. G. The Basic Rocks of Northeastern Maryland, and their Relation to the Granite. Amer. Geol., vol. 28, 1901, pp. 135 176.

(71) Lewis, H. C. A Great Trap Dike across Southeastern Pennsylvania. Amer. Philos. Soc. Proc., vol. 22, 1885, pp. 434–456.

(72) Mackin, J. H. The Problem of the Martic Overthrust and the Age of the Glenarm Series in Southeastern Pennsylvania. Jour. Geol. vol. 43, 1935, pp. 356–380.

(73) Mathews, Edward B. Anticlinal Domes in the Piedmont of Maryland. Johns Hopkins Univ. Circ. 26, no. 199, 1907, pp. 615–622.

(74) ——— Correlation of Maryland and Pennsylvania Piedmont Formations. Geol. Soc. Amer. Bull. 16, 1905, pp. 329–346.

(75) Mathews, Edward B. and Miller, W. J. Cockeysville Marble. Geol. Soc. Amer. Bull. 16, 1905, pp. 347–366.

(76) Mathews, Edward B. The Structure of the Piedmont Plateau as shown in Maryland. Amer. Jour. Sci., vol. 17, 1904, pp. 141–159.

(77) ——— The Mineral Resources of Cecil County, Maryland. Md. Geol. Survey, Cecil County, 1902, pp. 195–226.

(78) Miller, B. L. Age of the Schists of the South Valley Hills, Pennsylvania. Geol. Soc. Amer. Bull. 46, 1935, pp. 715–756.

(79) Miller, W. J. Origin of Foliation in the Pre-Cambrian Rocks of Northern New York. Jour. Geol. vol. 24, 1916, pp. 586–619.

(80) ——— The Crystalline Limestones of Baltimore County, Maryland. Johns Hopkins Univ. Diss, 1905, 189 pp.

(81) Mouret, G. Aperçu sur la Géologie de la Partie Sud-Ouest du Plateau Central de la France. Serv. de la Carte Géol. de la France. Bull. vol. 11, no. 72, 1899, 38 pp.

(82) Pabst, Adolf. Observations on Inclusions in the Granite Rocks of the Sierra Nevada. Univ. Calif. Publ. Dept., Geol. Sci. Bull, 17, 1928, pp. 325–386.

(83) Pietsch, K. Abgrenzung, geologisches Alter und tektonische Stellung des Sächsischen Granulitgebirges. Centralbl. f. Min. Geol. etc., 1922, pp. 265–277.

(84) Perclik, K. Zur Tektonik und Metamorphose der Moravischen Aufwölbungen am Ostrande der Böhmischen Masse. Geol. Rundschau, vol. 18, 1927, pp. 81–103.

(85) Ross, C. S. Origin of the Copper Deposits of the Ducktown Type in the Southern Appalachian Region. U. S. Geol. Survey, Prof. Paper 179, 1935, 165 pp.

(86) Sander, B. Petrofabrics (Gefügekunde der Gesteine) and Orogenesis. Amer. Jour. Sci. vol. 28, 1934, pp. 37–50.

(87) ——— Gefügekunde der Gesteine. J. Springer, Wien, 1930, 352 pp.

(88) ——— Zur petrographisch-tektonischen Analyse. Jahrb. d. k. k. Geol. Bundesanstalt, I–III, Wien, 73, 1923 pp. 183 253; 75, 1925 pp. 181–236; 76, 1926 pp. 323–406.

(89) Schmidt, W. Tektonik und Verformungslehre. Gebr. Borntträger, Berlin, 1932.

(90) Scholtz, H. Zur inneren Tektonik einiger Intrusivkörper aus dem Saar-Nahe-Gebiet. Centralbl. f. Min., Geol. etc., 1933-B, pp. 605–615.

(91) ——— Faltung und Schieferung im Ostsauerländer Hauptsattel. Centralbl. f. Min., Geol., etc. 1932-B, pp. 321–335.

(92) ——— Das varistische Bewegungsbild. Fortschritte der Geol. and Pal., vol. 25, 1930, pp. 235–316.

(93) SCHWINNER, R. Die Konsequenz in der tektonischen Entwicklung, erläutert am Gebirgsbau Europas. XVI Intern. Geol. Congress, 1933, Rept. Vol. II, 1936, pp. 983–992.

(94) SEDERHOLM, J. J. On Migmatites and Associated Pre-Cambrian Rocks of Southwestern Finland. Comm. Géol. de Finlande, Bull. 58, 1923, 153 pp; 77, 1926, 143 pp.

(95) ——— ——— On Synantectic Minerals and Related Phenomena. Comm. Géol. de Finlande, Bull. 48, 1916, 148 pp.

(96) ——— Über ptygmatische Faltungen. Neues Jahrb. f. Min. Geol. etc. B. B. 36, 1913, pp. 491–512.

(97) SENG, HERMANN. Beiträge zur petrographisch-tektonischen Analyse des sächsischen Granulitgebirges. Min. and Petr. Mitt., vol. 45, 1934, pp. 373–423.

(98) SINGEWALD, J. T., JR. Weathering and Albitization of the Wissahickon Schist at the Prettyboy Dam, Baltimore County, Maryland. Geol. Soc. Amer. Bull. 43, 1932, pp. 449–468.

(99) STOSE, G. W. and JONAS, A. I. Geology and Mineral Resources of the Middletown Quadrangle, Pennsylvania. U. S. Geol. Survey Bull. 840, 1933, 86 pp.

(100) SUESS, F. E. Europäische und Norkamerikanische Gebrigszusammenhänge. XVI Intern. Geol. Congress 1933, Rept. vol. ii, 1936, pp. 815–828.

(101) VAN HISE, C. R. Principles of North American Pre-Cambrian Geology. U. S. Geol. Survey, 16th Ann. Rept. pt. 1, 1896, pp. 571–874.

(102) WATSON, E. H., The Pegmatites of Maryland with Discussion of Associated Phenomena. Johns Hopkins Univ. Diss. 1929, 352 pp.

(103) WENCK, Ed. Kritik und Umdeutung der "Tektonischen Folgerungen aus Graubündener Quartzgefügediagrammen" von H. Closs. Schweiz. Min. Petr. Mitt., vol. 16, 1936, pp. 183–194.

(104) WILLIAMS, G. H. The General Relations of the Granitic Rocks in the Middle Atlantic Piedmont Plateau. U. S. Geol. Survey. 15th Ann. Rept., 1895, pp. 651–684.

(105) ———— The Geology of Baltimore and its Vicinity, pt. 1. Guide to Baltimore. Amer. Inst. Min. Eng., 1892, pp. 77–124.

(106) ——— The Petrography and Structure of the Piedmont Plateau in Maryland. Geol. Soc. Amer. Bull. 2, 1891, pp. 301–322.

(107) ——— The Non-Felspathic Intrusive Rocks of Maryland and the Course of their Alteration. Amer. Geol. vol. 6, 1890, pp. 35–49.

(108) ——— The Gabbros and Associated Hornblende Rocks occurring in the Neighborhood of Baltimore, Maryland. U. S. Geol. Survey Bull. 28, 1886, 78 pp.

(109) ——— On the Paramorphosis of Pyroxene to Hornblende in Rocks. Amer. Jour. Sci., vol. 28, 1884, pp. 259–268.

(110) ——— Note on the so-called Quartz-Porphyry at Hollins Station North of Baltimore. Johns Hopkins Univ. Circ. vol. 3, 1884, p. 131.

(111) WILLIS, B. The Mechanics of Appalachian Structure. U. S. Geol. Survey. 13th Ann. Rept., pt. ii, 1893, pp. 211–281.

(112) WINCHELL, HORACE. A New Method of Interpretation of Petrofabric Diagrams. Amer. Mineralogist. vol. 22, 1937, pp. 15–36.

(113) WURM, A. Über den Bauplan des variskischen Gebirges am Westrand der Böhmischen Masse. Geol. Rundschau, vol. 17, 1926, pp. 241–257.

(114) ——— Tektonische und magmatische Analyse des alten Gebirges im Norden von Bayern. Centralbl. f. Min., Geol. etc., 1923, pp. 532–542; 561–575.

Maps

(115) Topographic and Geologic Survey of Pennsylvania. Map of Pennsylvania showing the Geological Formations. 1931. 1: 380, 160.

(116) Maryland Geological Survey. Map of Maryland showing the Geological Formations. 1933. 1: 380, 160.

(117) Maryland Geological Survey. Map of Baltimore County and Baltimore City showing the Geological Formations. 1925. 1: 62, 500.

(118) Maryland Geological Survey. Map of Cecil County showing the Geological Formations. 1902. 1: 62, 500.

(119) Maryland Geological Survey. Map of Harford County showing the Geological Formations. 1904. 1: 62, 500.

(120) Virginia Geological Survey. Map of Virginia showing the Geological Formations. 1928.

VITA

John Marshall was born in Baltimore, Maryland in 1910. He attended the Boys Latin School in that city from 1922–1929 and entered the undergraduate school in the College of Arts and Sciences of the Johns Hopkins University in the fall of that year. In May 1932 he was admitted under the New Plan to the Department of Geology in which the following four years were spent in preparation for the degree of Doctor of Philosophy.

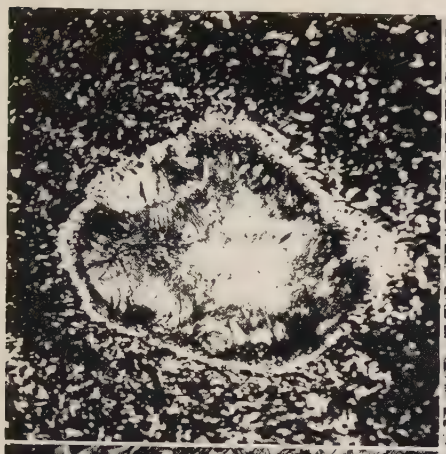


FIG. 1

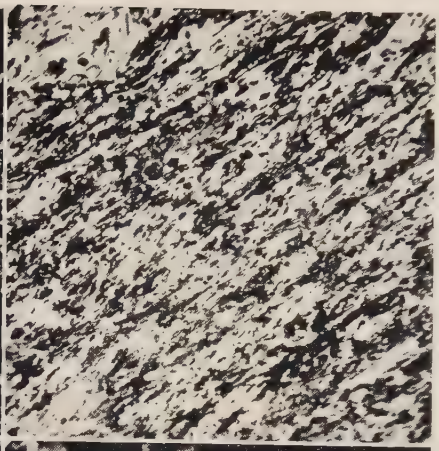


FIG. 2

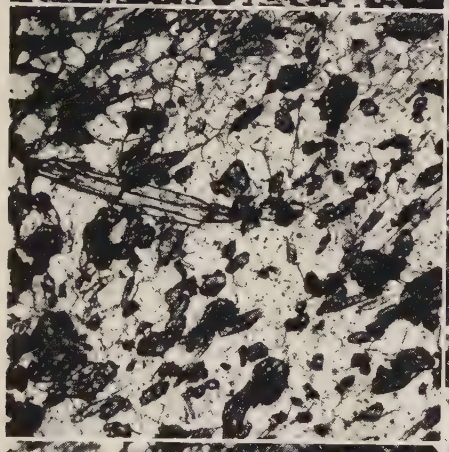


FIG. 3

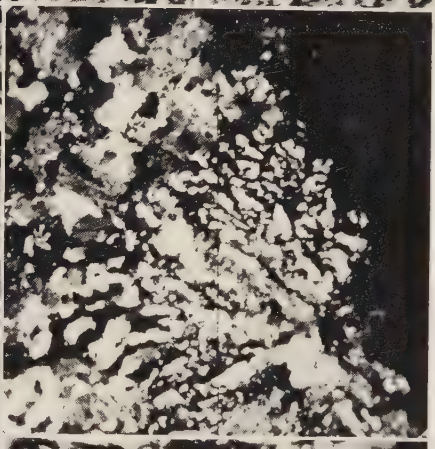
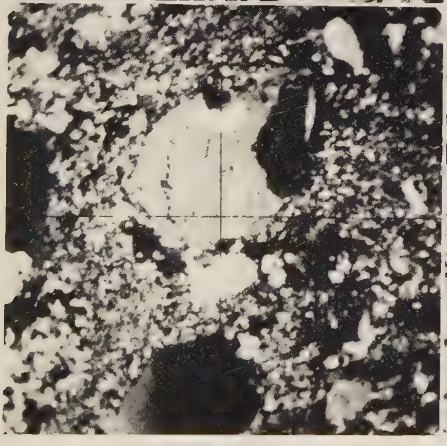


FIG. 4



IG. 5

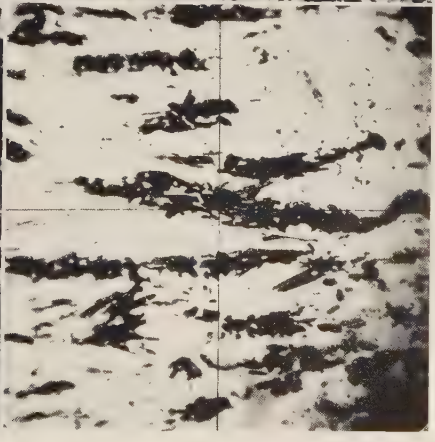


FIG. 6

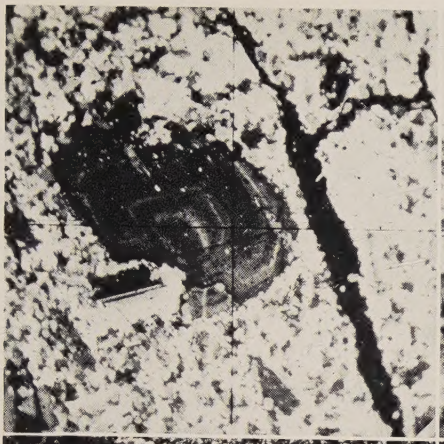


FIG. 1

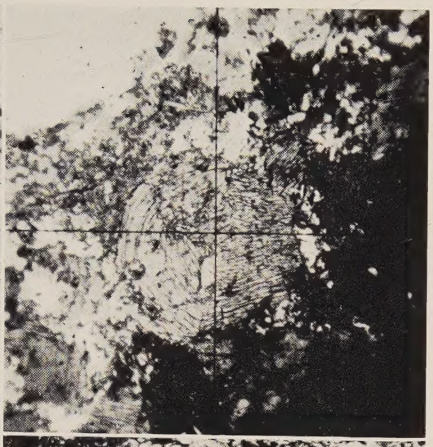


FIG. 2

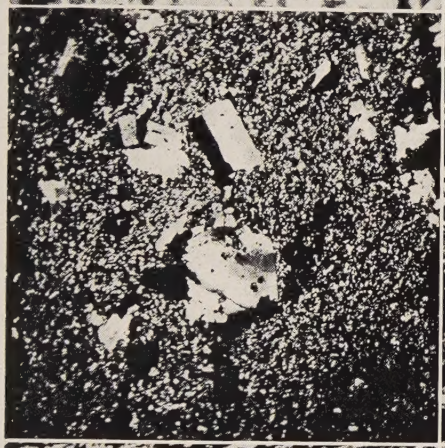


FIG. 3

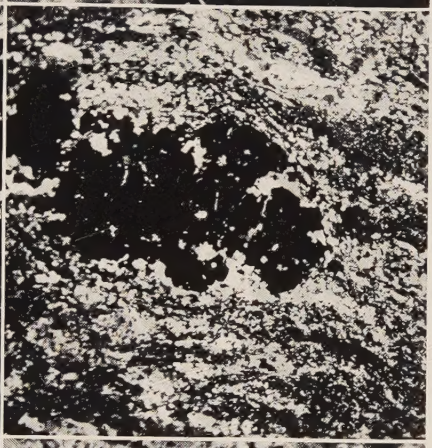


FIG. 4

FIG. 5

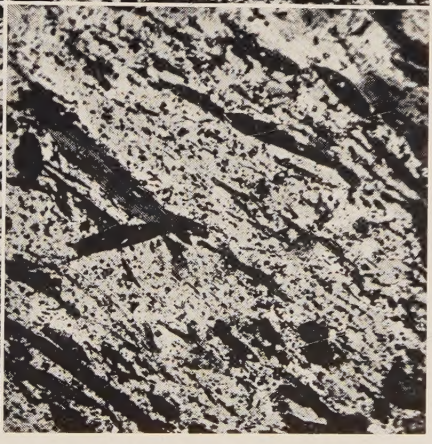


FIG. 6